Support Document for the public consultation period for the International Joint Commission's Lake Champlain-Richelieu River Flood Study

February 2022 (Draft)

The contents of this document have been developed contemporaneously with the completion of important activities, such as the public consultation process, final development of supporting documents, and with the refinement and continued iteration of Study Board Recommendations. Therefore, please be advised that this is a study "in process" and this document reflects what is known "at the moment" and the final findings, recommendations, as well as the validation of remaining information will change as the Study Board moves towards an end-of-March, 2022 conclusion to its work.

Study findings and recommendations as of January 28, 2022; subject to change. The final report is scheduled for release in April 2022.

A Note from the Study Co-Chairs

Following catastrophic flooding along the shorelines of Lake Champlain and the Richelieu River in Quebec during the spring of 2011, the governments of Canada and the United States asked the International Joint Commission (IJC) to review the causes and develop potential solutions to minimize impacts of future flooding in communities across the basin. The International Lake Champlain-Richelieu River Study Board was established in 2016. Since then, groups of experts have investigated scientific, engineering, environmental and socio-economic aspects of the problem and developed draft recommendations that can offer real, long-term benefits that reduce flooding and its impacts on the Lake Champlain and Richelieu River communities. The Study has prioritized learning from past experiences and current perspectives of citizens, speaking with community leaders and organizations about emergency response, economics, social and environmental concerns, as well as consulting decision-makers in federal, state, and provincial governments. These important social, political and economic considerations were integrated with modern scientific models to improve real-time flood forecasting in both countries and collaborative tools to support effective decision-making. As a result, the Study's draft recommendations reflect the concerns of basin communities in both countries and support workable approaches to reduce flooding and its impacts. Water level extremes of a system like the Lake Champlain and Richelieu River watershed can never be completely controlled, especially in the face of a changing climate. Nevertheless, thoughtful structural and non-structural approaches can be implemented over time to improve community resilience and reduce risks to life and property.

Jean-François Cantin, Canada Co-Chair *Deborah H. Lee, United States Co-Chair*

The members of the Study Board were appointed by the International Joint Commission to provide the expertise needed to prepare this report. Although they are employed by government agencies in both Canada and the United States, they serve the Commission in their personal and professional capacities and not as representatives of their agencies. The report was developed by the Study Board and should not be considered as official opinions, positions, or commitments of any organizations, agencies or departments named in this report.

Report Contents

This report addresses some of the key findings from the multi-year Lake Champlain-Richelieu River Study (the Study) and is organized around a set of four questions:

- **How did we get where we are today?**
- **What has the IJC done to try to find solutions?**
- **What should be done in the future?**
- **What comes next?**

Study Themes

The Study is based on cutting edge science and includes public engagement elements, interwoven throughout, to produce a set of draft recommendations that are summarized here. The icons below reflect the four Study themes (Figure 1) and are used in the report to identify areas where the themes are discussed in more detail. Findings and draft recommendations are highlighted with a magnifying glass icon. 

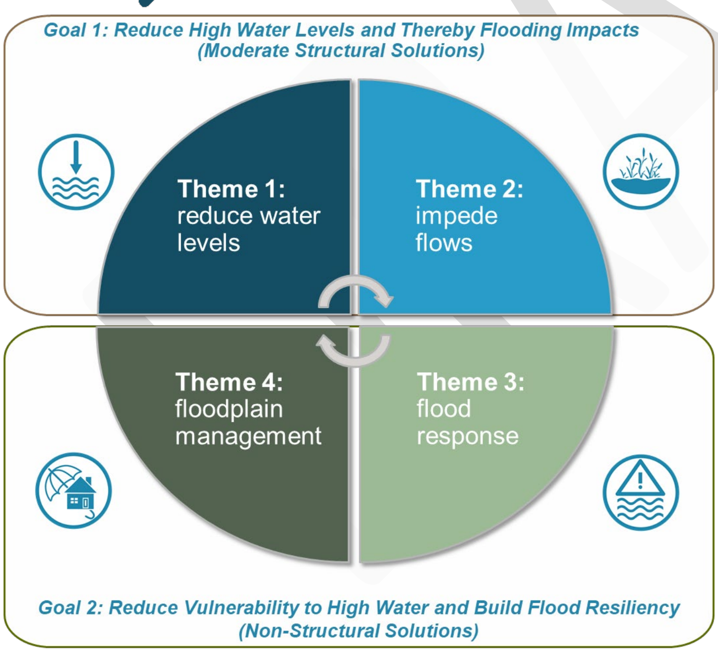


Figure 1. LCRR Study framework and primary themes

The Study analyses included the following objectives:

- Understanding causes and impacts of past floods
- Identifying floodplain best management practices
- Developing flood adaptation strategies
- Evaluating a binational real-time flood forecasting and mapping system
- Exploring potential flood management and mitigation measures, including both non-structural and moderate structural measures
- Analyzing social and political perception to measures

Study findings and recommendations as of January 28, 2022; subject to change. The final report is scheduled for release in April 2022.

Criteria for Evaluating Recommendations

To evaluate its recommendations, the Board identified seven decision criteria:

- Within the scope and mandate of this binational study, which stipulates only moderate structures will be considered
- Implementable, consistent with feedback from stakeholders, agencies and elected officials
- Technically viable, based on sound engineering and effective in reducing flood damages
- Economically viable, with benefits that exceed the cost, and not cost-prohibitive
- Fair and equitable, broadly benefitting society and not particular interest groups, nor having disproportionate negative impacts on a particular group
- Environmentally sound, protecting key ecosystem services and having minimal detrimental impacts
- Resilient to climate change, providing benefits across a wide range of possible climatic scenarios

Potential measures to reduce flooding and its impacts were evaluated through the lens of these criteria.

Recommendations

Reduce water levels:

The Study Board recommends the IJC advise governments that it is possible to achieve a modest relief of flood (on the order of 10 cm on the Lake and 15 cm at Saint-Jean-sur-Richelieu for an event like the 2011 flood) and drought water levels by returning the hydraulic regime at the Saint-Jean-sur-Richelieu shoal to a more naturalized hydraulic state. This can be achieved by removing some flow-impeding human artifacts in addition to some selected excavations of the shoal and installing a submerged weir in the area of the Saint-Jean-sur-Richelieu shoal. From the Study's evaluation of the proofs of concept, this moderate structural solution is technically feasible, economically beneficial, and socially acceptable. Also, based on the Study's analysis with environmental performance indicators, it appears that the structural solution has positive environmental impacts and no significant negative environmental impacts.

If desired, additional flood relief can be gained through combining the removal of the artifacts, selected excavations of the shoal, and the submerged weir with a modest water diversion through the Chambly Canal (for a total water level reduction of 15 cm on the Lake and 20 cm at Saint-Jean-sur-Richelieu for an event like the 2011 flood). While this alternative that includes the Chambly Canal water diversion is less economically performant, this addition brings greater water level relief for larger flood events and should be presented to the governments for their considerations.

If the governments decide to implement a structural solution, a process should be put in place to analyze binational social, political, environmental and economic implications of the final structure design and operation.

Impede flows:

The Study Board recommends that the IJC encourage the governments to continue protection of existing wetlands, as they provide flood relief (reduction of the peak water level by 15 cm in Lake Champlain and 12 cm in the Richelieu River during a 2011-scale flood) at the scale of lakeshore and Richelieu riverfront communities.

The Study Board recognizes that wetlands reduce local tributary flooding, support biodiversity, and have important environmental co-benefits. Consequently, the Study Board wishes to encourage governments to continue to protect these existing wetlands and, where possible, to restore lost wetlands and create new ones.

However, the LCRR Study has determined that without the creation of a very large area of new wetlands, there cannot be significant flood mitigation at the scale of lakeshore and Richelieu riverfront communities during major flood events. Therefore, the Study Board does not recommend pursuing a strategy for acquiring land and creating new wetlands as a flood management policy for lakeshore and Richelieu riverfront communities.

Flood response:

The Study Board recommends that all of the weather and hydrological information generated by NOAA[1] (in the United States) and ECCC[2] and MELCC[3] (in Canada) be made available to and used by the respective agencies responsible for the production and dissemination of flood forecasts, guidance and warnings.

- Continuation and enhancement of the collaboration between the various Agencies, namely NOAA, ECCC and MELCC, must be encouraged to ensure all available forecast data and their interpretations are shared in real time, with the ultimate goal that the official forecasts on each side of the border are of the highest possible quality and are accompanied by a concerted and consistent cross-border interpretation.
- Improved modelling and forecasting tools developed for the Lake Champlain-Richelieu River basin can greatly aid flood response planning and should be maintained. They showed the possibility of extending the forecasting horizon and providing new operational products relevant to the basin's stakeholders, such as water set-up, waves, flood extent and depth, and their consequences on the shore, for example: roads cut off, social vulnerabilities, and monetary impacts.

On that basis, the governments are encouraged to operationalize the improved modelling and forecasting tools and coherent risk assessment systems and

[1] US National Oceanographic and Atmospheric Association
[2] Environment and Climate Change Canada
[3] Ministère de l'Environnement et de la Lutte contre les changements climatiques (Ministry of the Environment and the Fight Against Climate Change)

support/maintain them after the Study. The LCRR tools, supporting data and documentation should be transferred to appropriate agencies in Canada and the US by no later than the end of 2022.

To support flood preparedness, simulations of flooding of various magnitudes and the related maps produced should be made available to all interested parties by no later than the end of 2022.

Floodplain management:

The Study Board recommends also that the IJC encourage the governments to make the best use, in relation with their own context, of the LCRR Study's analysis of best practices related to risk mapping, risk communication, floodplain management and flood insurance.

- Enhance flood risk mapping for targeted audiences. This includes updating and adding more details to existing flood risk maps.
- Develop flood risk communication campaigns designed for specific target audiences within the LCRR basin.
- Consider floodplain occupancy through the lens of resiliency. This includes land use strategies that avoid, accommodate and retreat from flooded areas, updating and strengthening the enforcement of land use regulations based on flood risk, and shielding development in high-risk flood zones.
- Explore and/or expand flood insurance. This includes further investigation of the state of flood insurance in the watershed and promoting an insurance arrangement that shares financial liability for flood damages.

How did we get where we are today?

The Lake Champlain-Richelieu River (LCRR) basin (Figure 2) is a large international watershed in southern Québec and northern New York and Vermont, rich in natural landscapes, history and vibrant communities. It is a region of wide-ranging geography – a deep lake surrounded by the rugged, mountainous terrain of the Adirondacks to the west and the Green Mountains to the east, flowing to the north into flat, fertile farmland along the river that extends to the St. Lawrence River. It is also, as recent history suggests, a region vulnerable to flooding. Severe floods have occurred multiple times in the past 100 years.

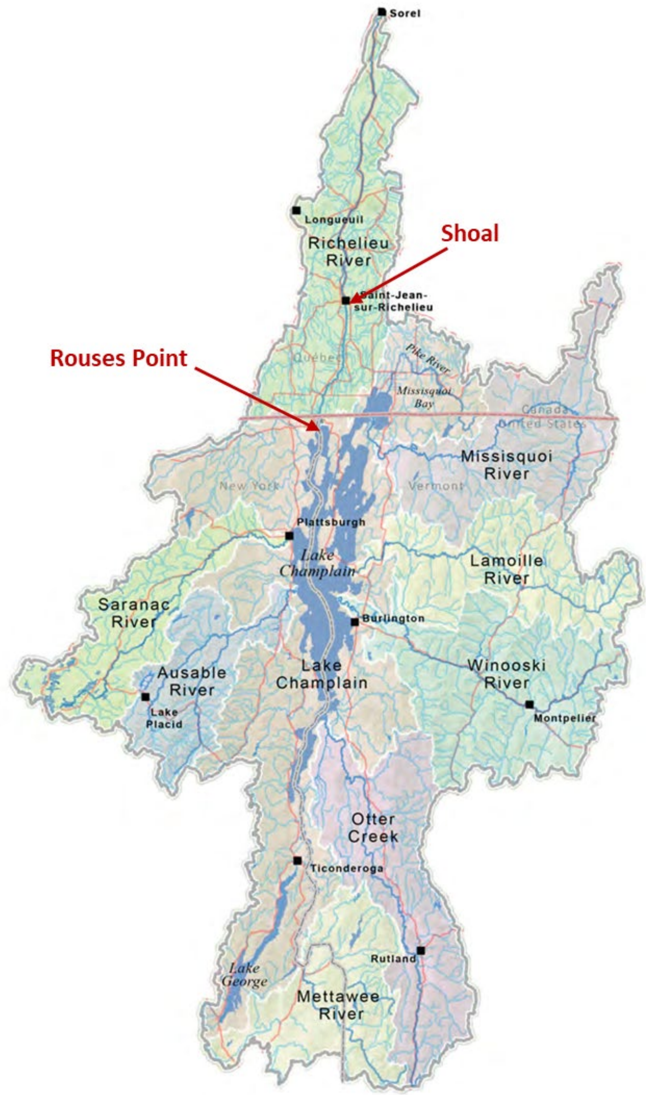


Figure 2. Lake Champlain-Richelieu River Watershed

A combination of topography and climate makes the LCRR basin naturally prone to extended periods of flooding. The steep mountain slopes of the upper basin, the flow regime of the upper Richelieu River, strong winds and large waves, high winter snowfall amounts, and the frequency of heavy spring rainfall are all key drivers of flooding in this basin. The dominant hydrological event of the year is the spring snowmelt, when nearly one-half of the annual streamflow can occur within an eight-week window. Figure 3 shows water levels from mid-March through June for several major flood events that occurred between 1990 and 2019 and illustrates both the magnitude and duration of these events.

In addition to the natural topographic and climatic factors, anthropogenic (human-caused) changes in the basin, including land-use changes (e.g., draining and filling wetlands), channel modifications (installing structures in the river), and construction of buildings, roads and infrastructure in areas prone to flooding have contributed to flooding and flood damage in the basin.

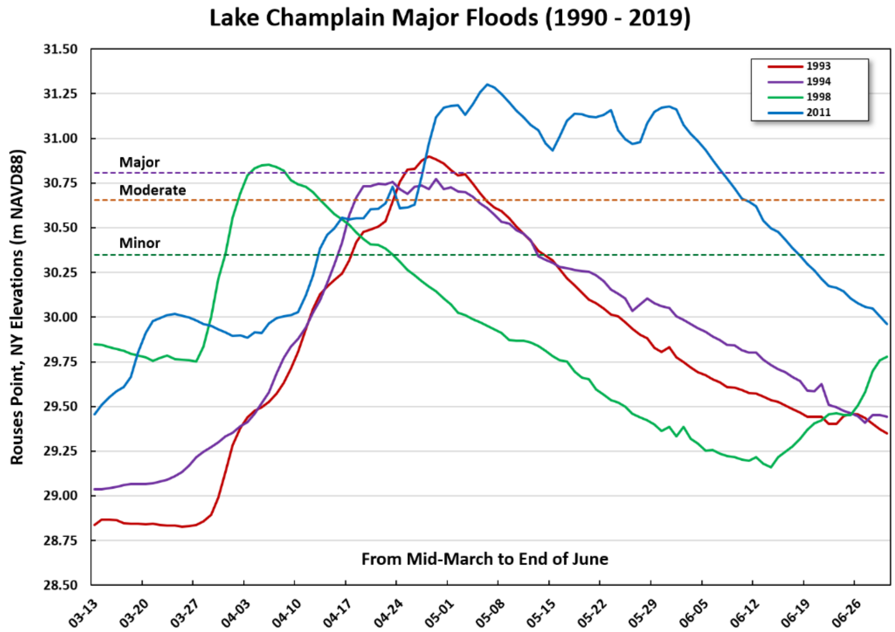


Figure 3. Spring water levels at Rouse's Point, New York during Lake Champlain major floods, 1990-2019[4]

The floods that have occurred over the past century have often resulted in studies and recommendations of mitigation measures. For example, in the 1930s, the implementation of a dam project in the Richelieu River was recommended. Construction was initiated not far from what is now known as the Fryers Island Dam, about 9 km (5.6 mi) downstream of Saint-Jean-sur-Richelieu, Quebec, and excavation upstream of the shoal was started. However, work was halted at the outbreak of World War II, and the dam project was never completed. A study in the 1970s suggested construction of a gated structure in the river at Saint-Jean-sur-Richelieu, but such a structure did not receive political support in the United States. This study also recommended flood forecasting, implemented in the United States first and in Canada much later, and flood plain mapping, which was carried out in both countries. Other policy actions were also taken to reduce flood damages. Although there have been prior studies and recommendations regarding flooding in the basin, they have been limited in their ability to address the problem. Further, there are concerns that the magnitude, frequency and economic severity of flooding could increase over time due to a changing climate and development in the floodplain.

In the spring of 2011, the region experienced flooding well beyond anything seen over the last century. Lake Champlain's water levels far exceeded the previous historical maximum level. The Richelieu River rose above flood stage for more than two months. Many farms and an estimated 4,000 homes along the Richelieu River in Québec and along the shoreline of Lake Champlain were damaged (Figure 4). More than 40 communities were directly affected, and thousands of residents needed to be evacuated. While

[4] Flood Management and Mitigation Measures Technical Working Group and Hydrology, Hydraulics, and Mapping Technical Working Group (FMMM/HHM), 2021. *Potential Structural Solutions to Mitigate Flooding in the Lake Champlain-Richelieu River Basin. International Lake Champlain – Richelieu River Study*. A report to the International Joint Commission. https://ijc.org/en/lcrr/potential-structural-solutions-mitigate-flooding-lake-champlain-richelieu-river-basin

damages had previously been estimated at more than CDN$110 million (US$82 million)[5], this assessment included primarily recorded residential damages, and not a broader set of impacts. A more comprehensive evaluation conducted with the Study's Integrated Social, Economic and Environmental System (ISEE) indicated that damages were about 70 percent higher, or about CDN$188 million (US$141 million)[6].

Figure 4. 2011 flooding, Colchester, Vermont (Photo credit: Matt Sutkoski)

The catastrophic 2011 flood was a new call to action and led the governments of Canada and the United States to request that the International Joint Commission (IJC) undertake a study into the causes, impacts, risks and solutions to flooding in the LCRR basin. The IJC is a binational treaty organization whose focus is to protect the waters shared by Canada and the United States, working toward solutions that are for the common good of both countries.

> The Study Board will make recommendations for consideration by the International Joint Commission and the Canadian and US governments; the governments make final decisions regarding whether recommendations will be implemented.

[5] International Lake Champlain and Richelieu River Study Board (ILCRRSB), 2019. *The Causes and Impacts of Past Floods in the Lake Champlain-Richelieu River Basin: Historical Information on Flooding*. A Report to the International Joint Commission. https://ijc.org/en/lcrr/causes-and-impacts-past-floods-lake-champlain-richelieu-river-basin-historical-information

[6] Flood Management and Mitigation Measures Technical Working Group and Hydrology, Hydraulics, and Mapping Technical Working Group (FMMM/HHM), in preparation. Evaluation of Potential Structural Solutions in the Richelieu River to Mitigate Extreme Floods

What has the IJC done to try to find solutions?

As mentioned above, the IJC was called upon previously to look into major flood events in the 1920s and 1970s. The current study reflects the call to action resulting from the spring 2011 flooding in the basin. In the spring of 2012, The governments of Canada and the United States asked the IJC to draft a plan of study to examine the causes and impacts of the 2011 flooding and develop possible mitigation measures. In the fall of 2014, a second mandate from the governments requested the collection of data, development of tools and creation of static floodplain maps. In 2016, the governments instructed the IJC to carry out activities described in the plan of study, leading the IJC to establish the Lake Champlain – Richelieu River Study Board. The Study Board oversees the Lake Champlain-Richelieu River Flood Study, which is an international collaboration involving individuals with expertise in engineering, flood management, planning and mitigation, as well as economics and social sciences. The inclusion of a team to study, from the onset, the social, political and economic drivers associated with flood mitigation is new to IJC studies and will provide useful insights for other studies in the future.

The Study has explored the causes, impacts, risks and solutions to flooding in Lake Champlain and the Richelieu River[7]. To do so, a framework was adopted for the Study that includes consideration of a variety of structural and non-structural[8] measures. The Study Board's flood mitigation framework focuses on four key mitigation themes:

Structural:

1. Reduce high water levels on the Richelieu River and Lake Champlain
2. Impede inflows into Lake Champlain or the Richelieu River through wetland and temporary upstream storage of floodwaters.

Non-structural:

3. Improve flood response (flood forecasting and emergency preparedness).
4. Enhance floodplain management (adaptation to flooding).

Experts identified, developed and evaluated potential flood mitigation measures under each of the four themes. Theme 1 focused on the development of moderate structures that lowered flood peaks, while Theme 2 evaluated the effectiveness of storing floodwaters within the watershed. In Theme 3, new state-of-the-science flood forecast models were developed, and Theme 4 explored new approaches to flood risk communication and flood insurance. Evaluations of ways to mitigate flooding and its impacts in the LCRR basin included developing and using sophisticated computer models to understand and

[7] The Study focuses on the reduction of flood impacts on the Richelieu River and Lake Champlain and does not directly address the reducing flooding and the impact of flooding on tributaries, although the impacts of more localized tributary flooding are recognized as often severe and relatively frequent.
[8] Non-structural measures differ from structural measures in that they focus on reducing the consequences of flooding instead of reducing the probability of flooding (they generally cause no changes to flood levels, velocities, duration, or the environment.) Non-structural measures can be temporary (contingent) or permanent.

simulate floods and flood impacts developing proposed mitigation solutions, and evaluating the acceptability of potential mitigation approaches. The Study developed a powerful tool, the Integrated Social, Economic and Environmental System (ISEE) to assist in understanding flood risk and evaluating potential solutions (Figure 5). ISEE can produce a variety of flood impact maps tailored to support an assessment of the possible mitigation measures. Other methods and models were used by various experts to answer specific questions such as those related to upland storage capacity or the potential effects of climate variability on flood adaptation strategies.

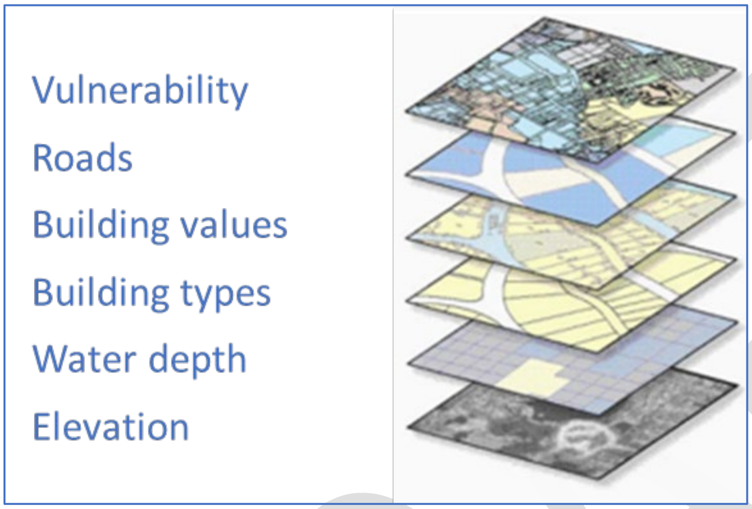


Figure 5. Integrated Social, Economic and Environmental (ISEE) System for assessing flood risk

To integrate social, political and economic considerations, social scientists used various methods such as conducting focus groups and surveys of the general public, emergency managers and planners, and elected officials to gauge risk perception, sources of risk communication and flood mitigation behaviors. Matters such as technical feasibility, cost, environmental impact and public preferences of specific structural changes were taken into consideration. Through these activities, the experts were able to understand how the public in each region of the basin perceived the risk of lake and riverine flooding, the anticipated impacts on their livelihoods, and their willingness to adopt certain risk mitigation measures and policies, as well as how they received risk communication messages.

For example, scientists found that, for many stakeholders, lake and river flooding are higher priorities in Quebec than in the United States. Stakeholders in both Canada and the United States place the highest priorities on protecting human health and safety, and support flood preparedness and adaptation measures, as well as nature-based solutions, over large structural interventions.

The Lake Champlain and the Richelieu River basin served, and continues to serve, as a resource for food, water, tools and spiritual practices for Indigenous peoples. Hunting, gathering, fishing, boating and recreation are important activities. There are cultural and archeological sites (campsites, villages, meeting sites, burial sites) of traditional and sacred importance to the Indigenous people across the basin. As such, the Study reached out to Indigenous communities with an interest in flood remediation in the basin and started a dialogue to make certain that the Study Board heard their concerns about cultural resources and practices that were impacted by past and present flooding in the basin. New knowledge was also incorporated into the indicator work, helping to ensure that the various flood mitigation measures considered took into account potential impacts on Indigenous communities. The dialogue continues during this consultation period.

Public and stakeholder engagement is an essential and ongoing component of the LCRR Study and includes both direct engagement by the Study Board (for example through public meetings) as well as a close collaboration with the Public Advisory Group (PAG). The binational PAG (Figure 6) represents various areas of interest within the Lake Champlain-Richelieu River basin. Its members drew on their knowledge, contacts and experience to provide advice and to encourage public participation in the Study by:

- Advising the Study Board on public consultation, involvement and information exchange;
- Serving as a conduit for public input to the Study process, and sharing Study outcomes;
- Reviewing and providing feedback on approaches, reports, products, findings and conclusions of the Study Board; and
- Recommending to the Study Board how to effectively meet the concerns of the public and stakeholders.

Figure 6. Members of the Public Advisory Group

Over the last two years, Study scientists increased their efforts to share research findings with the public through technical webinars and other public engagements. Members of the PAG and participants in surveys, focus groups, meetings, and workshops were key to the work of Study experts and the LCRR Study Board, and these contributions are greatly appreciated. Reports, videos, fact sheets and white papers on key aspects of the Study have been published on the Study website (www.ijc.org/lcrr), and a Study newsletter, *The Current*, was distributed on a bimonthly basis. Outreach coordinators played a key role in the multiple stakeholder and public meetings held throughout the Study.

The overall objective of these science and outreach activities was to develop a variety of potential flood mitigation measures and strategies that take into account technical, environmental, social and economic factors.

What should be done in the future?

Under the four Study themes, measures were identified that decrease flooding and its impacts and increase the resilience of lake and river communities to future high-water events. In conjunction with analysis of potential mitigation measures for the four primary themes, the Study examined future variability of water supplies under a changing climate, combining measures for greater impact, and enhancing binational collaboration.

Analysis of promising measures

Teams of experts from both Canada and the United States considered a range of potential measures to reduce flooding and its impacts. Promising measures were considered in light of the Study Board's mandate and decision criteria and provide the basis for the Board's recommendations.

Theme 1: Reduce water levels during flood events by structural measures

The Saint-Jean Shoal is the natural control point for water levels in the LCRR system. This means that it acts somewhat like a bottleneck for water flow, influencing water levels upstream (see Figure 7). To decrease maximum flood levels in the lake and alongside the river upstream of this point, accelerating the passage of water through this section would be key.

Figure 7. Aerial view of the Richelieu River at Saint-Jean-sur-Richelieu, looking downstream

Study scientists initially identified seven potential structural measures and assessed their effectiveness at reducing extremely high water levels, while sustaining water levels in the lake during low flow. These potential measures included various combinations of: selective removal of human-built structures to increase flow across the Saint-Jean shoal, diverting flow through the Chambly Canal along the side of the shoal, installing a fixed weir (submerged dam) upstream of Saint-Jean-sur-Richelieu, and installing an inflatable weir or bladder either upstream of Saint-Jean-sur-Richelieu or at the shoal. For each potential structural measure considered, study scientists conducted an initial assessment using the available information and data to determine whether it warranted further evaluation.

The Study was requested by the IJC not to consider major structural works and to focus on "moderate structural works." This eliminated further consideration of measures that involved the damming of the river (fixed or inflatable weirs). The unsuccessful history of trying to implement a dam on the river indicated a lack of support for a flood control structure of this size. The Study, therefore, focused its attention on measures involving selective removal of material from the river and diversion of water through the Chambly Canal, as these are moderate structural solutions. Specifically, three structural measures were explored in detail:

1. Selective excavation of the Saint-Jean-sur-Richelieu Shoal to remove human-made features and other selected areas of higher elevation on the shoal that act as a bottleneck, with a submerged weir to help moderate flow and avoid low water levels during dry periods
2. Diversion of significant flow (400 m^3/s) through the Chambly Canal during flood events to move water downstream more quickly to decrease water levels
3. Diversion of a moderate amount of flow (80 m^3/s) through the Chambly Canal, in conjunction with Measure 1 (selective excavation and submerged weir)

Analysis of the measures included assessment of technical feasibility, mapping natural and modified riverbed elevations, simulations of flow impacts and benefits associated with structural measures, development of thorough cost estimates, and exploration of potential operating plans. The analysis of these alternatives was conducted to provide a proof-of-concept design and it is recognized that additional work (e.g., detailed engineering plans, environmental impact assessment, etc.) would be required to implement any of these alternatives.

The diversion of a significant amount of water through the Chambly Canal (Measure 2) was examined by a technical committee, and both technical and economic problems were identified with this measure; Measure 2 is therefore not recommended.

Findings and recommendations:

The Study identified two promising structural measures that meet the evaluation criteria[9]. The structural solutions under consideration help return the Richelieu River to a more naturalized state of its hydraulic regime by removing some of the human modifications and shoal materials that impede river flow. This hydraulic regime provides lower water levels during floods compared to the current state, resulting in reduced damages in both the United States and Canada. It also includes the added benefit of keeping water levels higher during dry periods. The suggested measures show favorable financial benefits compared with the costs (Table 1), and neutral or positive environmental impacts for most key species or habitats considered in the review.

Table 1. Assessment of costs and benefits of structural measures

	Selective removal of shoal material + submerged weir	**Selective removal of shoal material + submerged weir + moderate Chambly Canal diversion**
Economic assessment		
Cost	CDN $8M (US$6.4M)	CDN$21M (US$16.8M)
Benefit/cost ratio (Canada only)	10.11	3.96
Water level assessment		
Decrease in Richelieu River level for 2011 flood	15.2 cm (6.0 in)	22.3 cm (8.8 in)
Decrease in Lake Champlain level, 2011 flood	10.7 cm (4.2 in)	15.2 cm (6.0 in)
Increase in Lake Champlain Level, 1965 drought	Up to 28.0 cm (11.0 in)	Up to 28.0 cm (11.0 in)
Impact assessment		
Homes saved from flooding, 2011 flood	596 (15.5%)	928 (24.2%)

The first promising structural measure combines the first two of the three elements below; the second solution includes all three of the following elements:

- Selective removal of material from the shoal in the Richelieu River at Saint-Jean-sur-Richelieu, including removal of unused human structures (submerged dikes and an ancient, not visible eel trap[10]) that remain in the river, to promote faster flow through this section.

[9] Flood Management and Mitigation Measures Technical Working Group and Hydrology, Hydraulics, and Mapping Technical Working Group (FMMM/HHM), in preparation. Evaluation of Potential Structural Solutions in the Richelieu River to Mitigate Extreme Floods

[10] The highly visible eel trap that is a landmark for the community will not be removed

- Reshaping of the eastern side of the upper shoal and construction of a submerged weir, using the excavated material, to keep the water levels in the upper river and lake from dropping too low during dry periods as a result of the shoal excavation.
- Creating box culverts and gates that would allow some river flow to be diverted through dikes into and out of a segment of the Chambly Canal between locks and adjacent to the narrowest part of the shoal; this would allow extra water to pass through this constricted area more quickly during flooding events. The diversion would be initiated when the water level reaches 29.25 m (95.96 ft).

These elements are shown in Figure 8. A key advantage of the submerged weir is that it can be constructed using the excavated materials, greatly reducing construction costs and providing a more natural substrate for aquatic life. The weir will not be visible except at extreme low flows, and it can be repaired or modified as needed in the future.

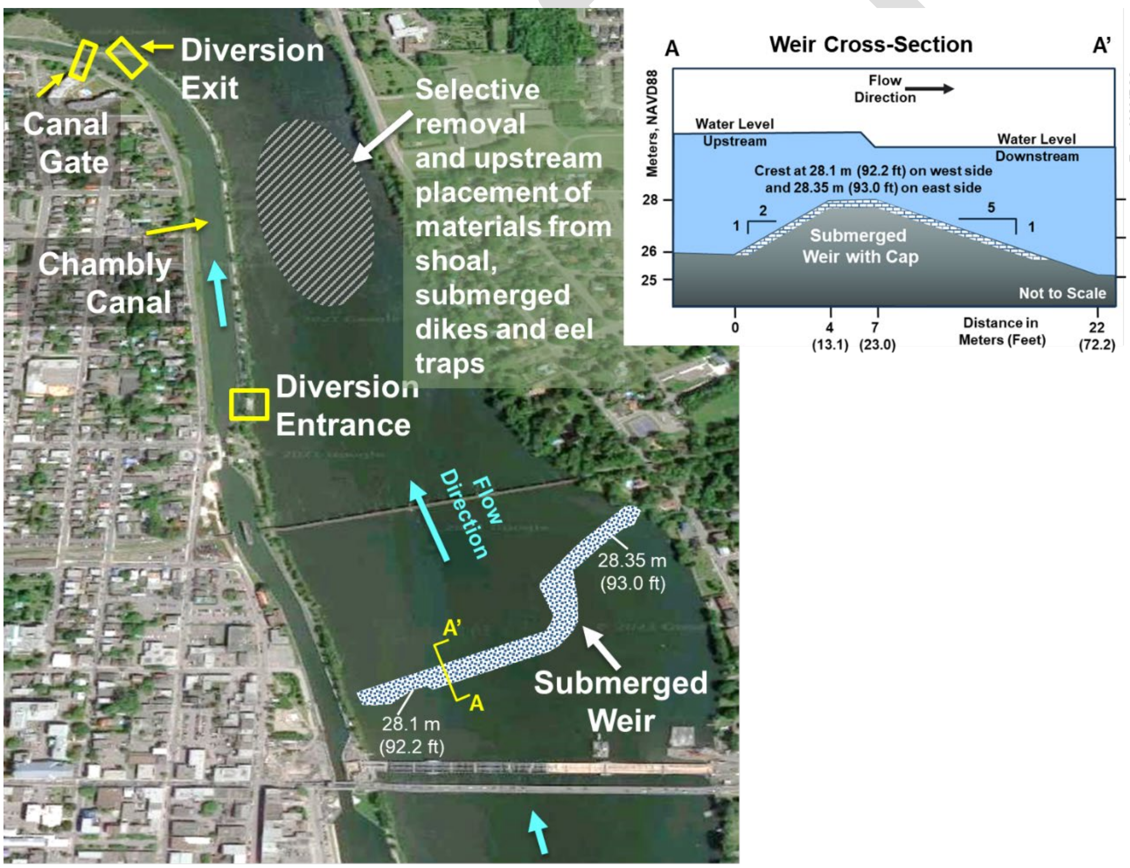


Figure 8. Schematic diagram of proposed excavation, weir construction and diversion through Chambly Canal at Saint-Jean-sur-Richelieu shoal

Recommendations

The Study Board recommends the IJC advise governments that it is possible to achieve a modest relief of flood (on the order of 10 cm on the Lake and 15 cm at Saint-Jean-sur-Richelieu for an event like the 2011 flood) and drought water levels by returning the hydraulic regime at the Saint-Jean-sur-Richelieu shoal to a more naturalized hydraulic state. This can be achieved by removing some flow-impeding human artifacts in addition to some selected excavations of the shoal and installing a submerged weir in the area of the Saint-Jean-sur-Richelieu shoal. From the Study's evaluation of the proofs of concept, this moderate structural solution is technically feasible, economically beneficial, and socially acceptable. Also, based on the Study's analysis with environmental performance indicators, it appears that the structural solution has positive environmental impacts and no significant negative environmental impacts.

If desired, additional flood relief can be gained through combining the removal of the artifacts, selected excavations of the shoal, and the submerged weir with a modest water diversion through the Chambly Canal (for a total water level reduction of 15 cm on the Lake and 20 cm at Saint-Jean-sur-Richelieu for an event like the 2011 flood). While this alternative that includes the Chambly Canal water diversion is less economically performant, this addition brings greater water level relief for larger flood events and should be presented to the governments for their considerations.

If the governments decide to implement a structural solution, a process should be put in place to analyze binational social, political, environmental and economic implications of the final structure design and operation.

Theme 2: Impede flow by increasing watershed storage to reduce flooding

Another way to reduce high water levels is to slow the entry of water into the Lake and River by storing water on the land or using other nature-based solutions. The study looked at (i) quantifying the flood reduction of existing wetlands (about 1,551 square kilometers or 599 square miles) (ii) quantifying the flood reduction impact of increasing wetlands of tributaries in Vermont and New York subwatersheds and (iii) assessing the potential of temporarily storing floodwater on riparian agricultural landscapes[11].

[11] Rousseau, A., S. Savary, M-L. Bazinet, 2021. *Flood water storage using active and passive approaches – Assessing flood control attributes of wetlands and riparian agricultural land in the Lake Champlain-Richelieu River watershed. 2019-2020.* A report to the International Lake Champlain-Richelieu River Study Board https://ijc.org/sites/default/files/LCRR_Watershed_Storage_Report_EN_01142022.pdf

Quantification of potential flood reduction was accomplished using a hydrological modelling platform, which subdivided the watershed into river segments and hillslopes, simulated the effect of land cover on flows, and provided input to a lake/reservoir water balance model and a model to predict lake or river water levels.

This assessment of the hydrological services provided by the existing wetlands (1,551 km^2 or 599 mi^2) located in the Lake Champlain basin indicated that for a flooding event of the magnitude of the 2011 flood, existing wetlands can reduce the Lake Champlain water level by 15 cm (5.9 in), the Richelieu River peak flow by 6.7 percent, and the Richelieu River water level by 12 cm (4.7 in). Also, existing wetlands stabilize low flows during droughts. It is therefore important that existing wetlands be preserved and protected.

In addition to evaluating existing wetlands, the study evaluated several scenarios involving increasing wetlands of tributaries in Vermont and New York subwatersheds (Figure 9), as well as temporarily flooding agricultural lands to store floodwaters. Adding 1,488 km^2 (575 mi^2) of wetland area (would provide additional flood relief, as shown in Table 2. The effect of temporarily flooding farmlands (2,256 km^2 or 871 mi^2) would provide some flood relief, but the water level reductions are lower than for adding wetlands.

Table 2. Effect of adding 1,488 km^2 of wetland in the Lake Champlain basin on high water levels in Lake Champlain and the Richelieu River

	Lake Champlain	Richelieu River
Average high-water reduction	8 cm (3.1 in)	6 cm (2.4 in)
Reduction for 2011 flood	12 cm (4.7 in)	10 cm (3.9 in)

Findings and recommendations

The Study demonstrated that existing wetlands provide significant flood relief, and the 2011 floods would have been much worse in the absence of these wetlands. For this reason, it is important that existing wetlands be preserved and protected. From a strictly technical perspective, additional wetlands could contribute to flood attenuation by passive water storage. However, adding wetlands and flooding farmland would require extensive land alteration and acquisition. Given existing policies, programs, and regulations in Canada and the United States, restoring and constructing new wetlands instead of flooding farmland would provide a socially-acceptable framework to build resilience over time in the basin, at least at the local subwatershed scale. Expanding wetlands to provide substantial flood relief for Lake Champlain and the Richelieu River, however, was determined to require a very large land area (about the size of Lake Champlain). The Study Board's preliminary benefit/cost evaluation suggested about $100 of cost for every $1 of benefit for reducing water levels at the basin scale. This measure is therefore not practical to implement, and is not a viable solution to major flooding in Lake Champlain and the Richelieu River.

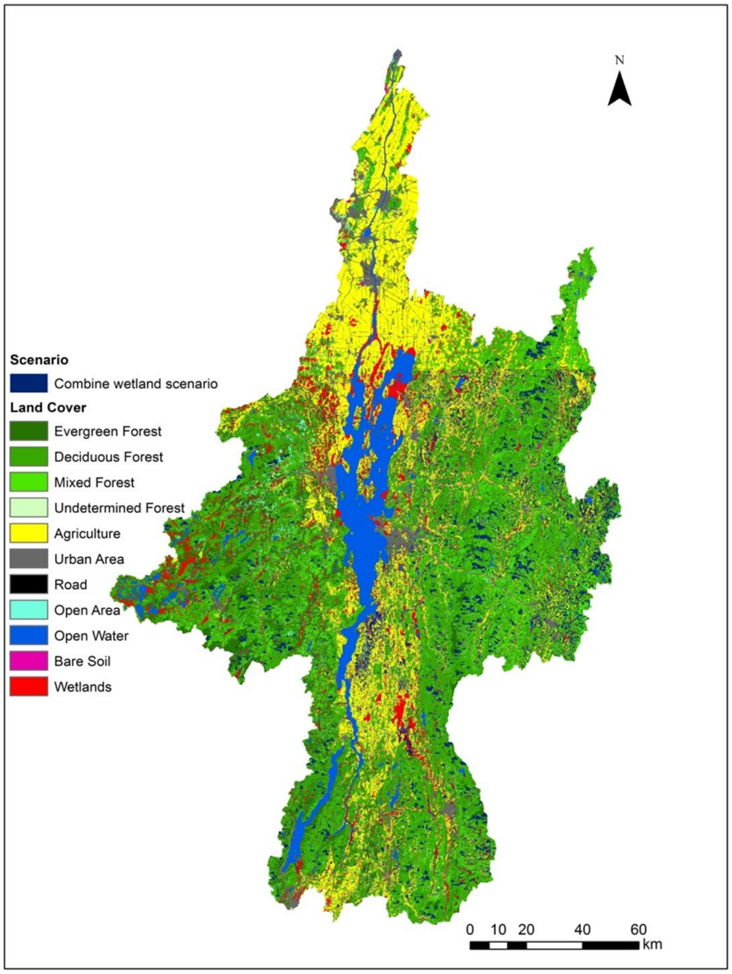


Figure 9. Areas of potential wetland storage (shown in dark blue)

Recommendations

The Study Board recommends that the IJC encourage the governments to continue protection of existing wetlands, as they provide flood relief (reduction of the peak water level by 15 cm in Lake Champlain and 12 cm in the Richelieu River during a 2011-scale flood) at the scale of lakeshore and Richelieu riverfront communities.

The Study Board recognizes that wetlands reduce local tributary flooding, support biodiversity, and have important environmental co-benefits. Consequently, the Study Board wishes to encourage governments to continue to protect these existing wetlands and, where possible, to restore lost wetlands and create new ones.

However, the LCRR Study has determined that without the creation of a very large area of new wetlands, there cannot be significant flood mitigation at the scale of lakeshore and Richelieu riverfront communities during major flood events. Therefore, the Study Board does not recommend pursuing a strategy for acquiring land and creating new wetlands as a flood management policy for lakeshore and Richelieu riverfront communities.

Theme 3: Respond to floods with better forecasts and planning to enhance resilience

Besides evaluating solutions that concern reducing high water levels, the Study considered a second goal: to reduce vulnerability to flooding and build flood resilience through improved preparedness.

Study activities related to improved forecasts and emergency planning fall into two areas:

- Improving flood forecasts and flood hazard mapping
- Exploring mapping flood impacts for emergency responses

Improving flood forecasts and flood hazard mapping

The Study evaluated flood forecasting systems in Quebec and the United States[12]. Flood forecasting relies heavily on the evolution in space and time of meteorological conditions such as temperature, liquid and frozen precipitation and solar radiation. In this context, the National Oceanographic and Atmospheric Administration (NOAA) in the United States and Environment and Climate Change Canada

[12] Flood Management and Mitigation Measures Technical Working Group and Hydrology, Hydraulics, and Mapping Technical Working Group (FMMM/HHM), in preparation. Development of a Binational Flood Forecasting and Real-time Floodplain Mapping System for Operational Implementation

(ECCC) in Canada operate numerical weather prediction systems ranking amongst the best in the world; this information is made available through an open data portal to the respective agencies responsible for the production and dissemination of flood forecasts, guidance and warnings.

In the United States, NOAA is the sole federal authority providing flood forecasts, guidance and warnings. In Canada, the provision of flood forecasts, guidance and warnings is a provincial responsibility. For the northern portion of the LCRR watershed, located in the Province of Québec, the responsible authority is the Ministère de l'Environnement et de la Lutte contre les Changements climatiques[13] (MELCC). Each agency is responsible for issuing official flood forecasts for its respective territories and producing coherent binational forecasts for the LCRR; there is no single binational official flood forecast. Experts have reviewed the programs and indicated that independent flood forecasts will continue to be used in the recommended flood forecasting system in the future. However, the various components (i.e., models) should continue to be deployed within ECCC, NOAA and MELCC in a collaborative manner.

Improvements in many components have occurred during the LCRR Study. In the United States, improved hydrologic models have been created for the LCRR basin; these modeling improvements increase the ability to produce flooding forecasts for the tributaries to Lake Champlain. A new experimental forecast system (Figure 10) produces forecasts of spatially variable lake level, circulation and wind waves in Lake Champlain and the Richelieu River system to provide a proof of concept of what advance warning of floods in the region can look like.

[13] Ministry of the Environment and the Fight Against Climate Change

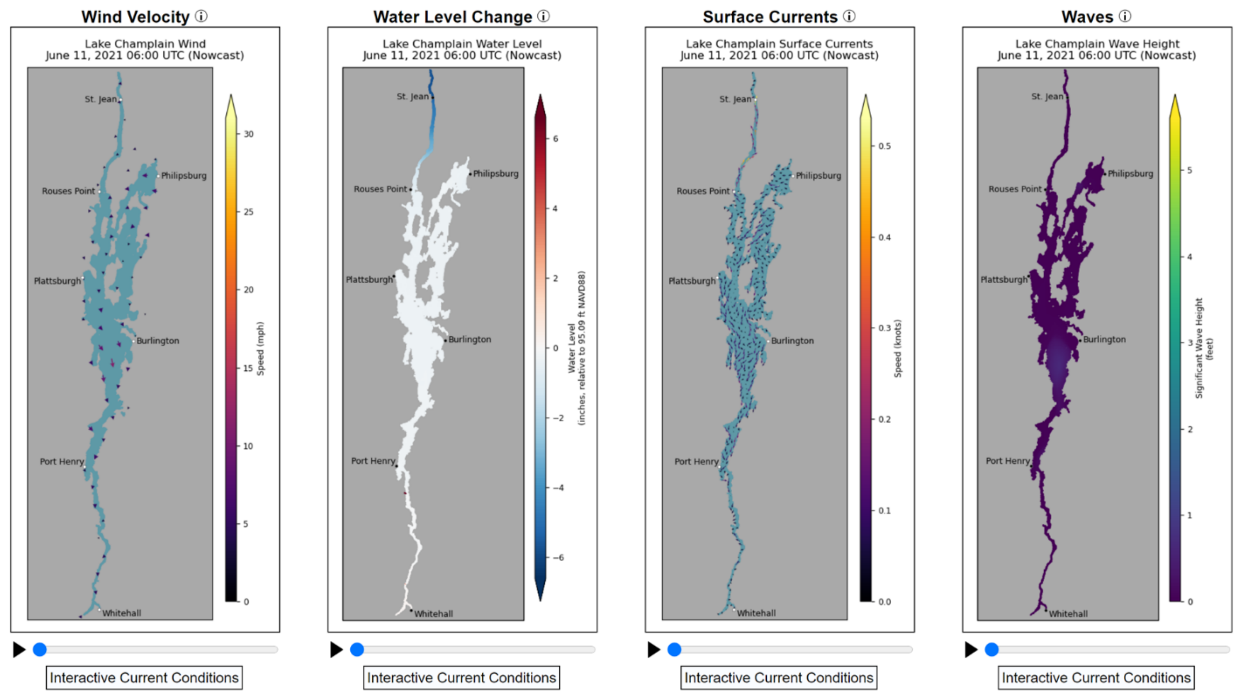


Figure 10. Example of flood forecasting improvements undertaken for Lake Champlain

An assessment of user needs highlighted that desired forecasting products include short-term inundation maps with associated probabilities of occurrence or exceedance of flooding limits, as well as long-term water level and flow graphs assessing the flood risk with ranges of probabilities. The recommended flood forecasting system will use the models (or similar ones) developed or improved during the LCRR Study that can capture the processes relevant to forecasting on the LCRR, such as winter snow accumulation and projected timing and volume of snowmelt, inflows to Lake Champlain, discharge through the Richelieu River, and effects of wind and waves on the system. These individual models and the coordinated use of groups of models in forecasting (ensemble forecasting) will support uncertainty assessment and inundation mapping with forecasts, as desired by users.

Explore mapping flood impacts for emergency responders

The Study looked at tools that could go beyond providing information on flood hazard (extent of flood and depth of water) to help local emergency responders prepare for upcoming flooding. The Study used the Integrated Social, Economic and Environmental system (ISEE) to evaluate flood risk beyond hazard (Figure 11). ISEE incorporates social risk such as vulnerability and can generate maps and information, such as extent of flood, depth of water, road access and location of people at risk, that can improve emergency responses to floods. One of the key features is that it provides information at a very high level of granularity (for example, for a given building, road or property), which can be very helpful for both emergency response and also for planning over a longer period of time.

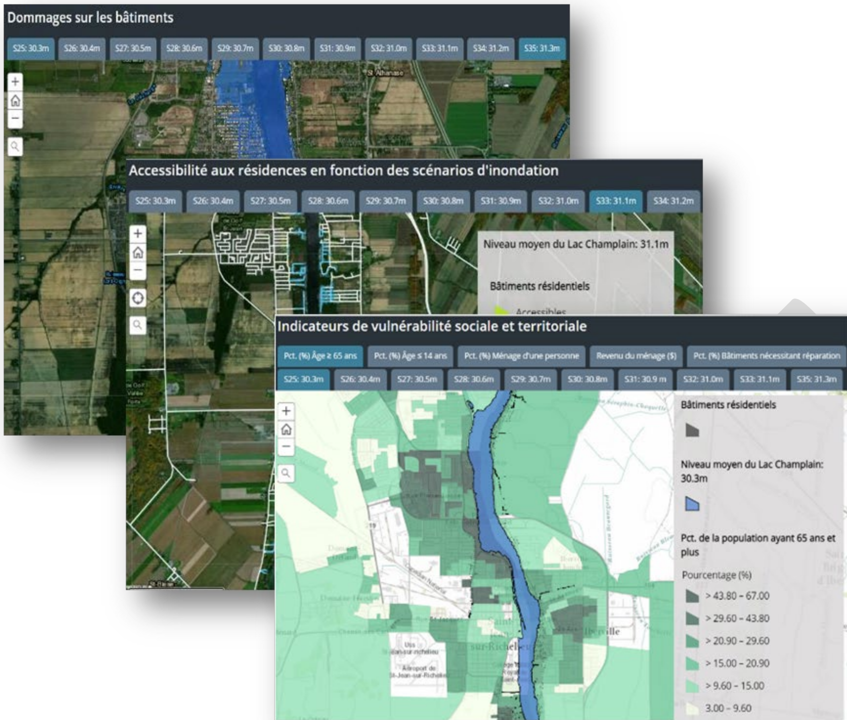


Figure 11. Integrated Social, Economic and Environmental (ISEE) mapping tool

Findings and recommendations

The study explored some potential improvements in modeling and forecast products. Operational agencies such as NOAA, ECCC and MELCC will have access to all of the tools developed in the Study. This will be helpful for them to increase forecast lead time to five days and to include inundation mapping in their operational systems such as the NOAA National Flood mapping initiative and the Quebec Info-Crue project that is underway. These tools will support individuals, communities and first responders in developing flood response plans.

Gap analysis of the current situation compared with the recommended system found that the required models are very close to ready for use, but still require some work to connect better with each other and to be deployed in operations. The work is on the right track and no major technical barriers exist. Some research is still required to find a proper integration methodology for multiple forecasts, but a hands-on approach by the forecasters can be leveraged in the meantime. The Study Board considers it important that the supporting agencies maintain their current collaboration and readily provide the required data to each other to maintain the forecasting chain.

Recommendations

The Study Board recommends that all of the weather and hydrological information generated by NOAA (in the United States) and ECCC and MELCC (in Canada) be made available to and used by the respective agencies responsible for the production and dissemination of flood forecasts, guidance and warnings.

- Continuation and enhancement of the collaboration between the various Agencies, namely NOAA, ECCC and MELCC, must be encouraged to ensure all available forecast data and their interpretations are shared in real time, with the ultimate goal that the official forecasts on each side of the border are of the highest possible quality and are accompanied by a concerted and consistent cross-border interpretation.
- Improved modelling and forecasting tools developed for the Lake Champlain-Richelieu River basin can greatly aid flood response planning and should be maintained. They showed the possibility of extending the forecasting horizon and providing new operational products relevant to the basin's stakeholders, such as water set-up, waves, flood extent and depth, and their consequences on the shore, for example: roads cut off, social vulnerabilities, and monetary impacts.

On that basis, the governments are encouraged to operationalize the improved modelling and forecasting tools and coherent risk assessment systems and support/maintain them after the Study. The LCRR tools, supporting data and documentation should be transferred to appropriate agencies in Canada and the US by no later than the end of 2022.

To support flood preparedness, simulations of flooding of various magnitudes and the related maps produced should be made available to all interested parties by no later than the end of 2022.

Theme 4: Floodplain management practices to enhance resilience

Under this theme, the Study sought non-structural approaches to increase the resilience of lakeshore and riverfront communities to flooding through floodplain management. These measures involve implementing a range of policy tools that prevent and reduce flood hazards, limit flood exposure and decrease social vulnerability to flood impacts, improving the general well-being of residents.

Flood risk is the product of three elements: (1) a flood hazard, meaning inundation by water of land that is normally dry; (2) the exposure of people, property, infrastructure, and economic activity in or near the flood hazard zone; and (3) the vulnerability of people and assets to harm from flooding.

The Study has produced information and tools to support the implementation of a flood risk management strategy. These will be important tools available after the Study is completed, and include:

- Flood forecasts and flood hazard maps that can be used by regional and local emergency managers to plan for preparedness and response;
- Climate Change scenarios and a decision approach to support decision making in the face of uncertainty;
- An Integrated Social, Economic, and Environmental (ISEE) modeling system, which provides localized estimates of flood damages to buildings and homes to evaluate the costs and benefits of risk reduction investments in the basin; and
- Assessments of the political feasibility and social acceptability of policy tools, including documenting support among emergency managers and planners, prioritization of equity in the distribution of benefits and costs, and integration of flood risk information into comprehensive land use plans and zoning regulations.

On the specific topic of Floodplain Management, four key areas of focus were each addressed by the development of a corresponding topical White Paper[14]:

- Flood maps
- Flood risk communication
- Floodplain occupancy management
- Flood insurance.

Best management practices compiled in these White Papers, based on a literature review and interviews with experts, were synthesized into a summary report for the floodplain management theme[15].

[14] White papers in preparation; citations to be added

[15] Integrative White Paper in preparation; citation to be added

Findings and recommendations

The Study finds that an effective flood risk management strategy should:

- be based on a comprehensive and continuous assessment of flood risk (i.e., hazard, exposure, and vulnerability);
- implement a portfolio of risk reduction tools to avoid, accommodate, and retreat from flood risk; and
- openly communicate flood risk to stakeholders and the public.

Drawing on the four White Papers produced under this theme, the Study identified four key policy tools that could be applied to reduce flood risk:

- Flood maps: These are a valuable resource for flood risk management, but they should be designed to target specific audiences, such as planners or the general public. Maps designed for public use should be dynamic, interactive, and user-friendly to achieve their full potential.
- Flood risk communication campaigns: Other than simply informing targeted audiences about their flood risk and actions they can take to reduce the risk, communication campaigns could also be used in this watershed to increase purchasing of flood insurance by at-risk property owners, encourage local emergency management, and inform potential buyers of at-risk properties, but messages should be designed using best practices.
- Floodplain management: This includes discouraging occupancy of flood-prone lands due to current risk and in anticipation of changes in future risk. However, existing development also faces flood risk, which should be reduced through temporary or permanent protections and building alterations whenever justified.
- Flood insurance: Insurance can be an effective tool to speed post-flood recovery, but securing widespread coverage will require sharing risk and responsibility between government and the private sector.

Those findings and reviews of best practices should be taken to the cognizance of appropriate level of governments in US and Canada as relevant information for them to analysis for their flood risk management activities in the LCRR.

The Study has produced a wealth of data and tools to support flood risk management in the LCRR basin:

- The Study has supported an enhanced flood forecasting system, including several models, that will enable real-time forecasts of lake levels, wave heights and river levels, to assist in planning for preparedness and response.
- The Study's "decision scaling" approach that incorporates uncertainty in climate change projections will aid in prioritizing risks and refining adaptation options.
- The ISEE system is a sophisticated tool to evaluate flood risk at the property level and estimate flood damages under varying water levels. This tool can be used to compare the costs and benefits associated with various potential mitigation measures.
- The study provides context for understanding the political feasibility and social acceptability of

potential measures to reduce flood risk. The inclusion of social, political and economic considerations from the outset provides a model for future studies. This work suggested that there is broad support for floodplain management policy solutions among emergency managers and planners, emphasized the importance of equity considerations and dialogue with stakeholders, recommended integrating flood resilience as a policy priority and suggested an adaptive management approach, implementing and evaluating pilot projects prior to "scaling up" to the basin as a whole.

Recommendations

The Study Board recommends also that the IJC encourage the governments to make the best use, in relation with their own context, of the LCRR Study's analysis of best practices related to risk mapping, risk communication, floodplain management and flood insurance.

- Enhance flood risk mapping for targeted audiences. This includes updating and adding more details to existing flood risk maps.
- Develop flood risk communication campaigns designed for specific target audiences within the LCRR basin.
- Consider floodplain occupancy through the lens of resiliency. This includes land use strategies that avoid, accommodate and retreat from flooded areas, updating and strengthening the enforcement of land use regulations based on flood risk, and shielding development in high-risk flood zones.
- Explore and/or expand flood insurance. This includes further investigation of the state of flood insurance in the watershed and promoting an insurance arrangement that shares financial liability for flood damages.

Consideration of future variability of water supplies under a changing climate

All the potential solutions to flooding resulting from the Study must be cognizant of the influence of our changing climate. Experts determined future climate scenarios from multiple perspectives and incorporated those into the recommendations. Climate is deeply uncertain, so no one prediction can be used for planning.

Key Study findings regarding climate change include:

- Predictions varied from slightly less to slightly more inflows to Lake Champlain. Despite deep uncertainty surrounding the climate system and its future evolution, the available information indicates that climate change is likely to reduce <u>average</u> Lake Champlain levels and Richelieu River flows during the 21st Century,

- Climate change will probably reduce the flood mitigation benefits of the proposed two structural measures, but the Study analysis suggests they are likely to remain cost-effective.
- Even if average Lake Champlain levels and River flows are reduced, the region will still be susceptible to floods greater than those experienced in 2011. It is, however, difficult to assign a probability of occurrence of such extreme and rare events. The best way to deal with them would not be to construct a large structure, but to consider them in emergency response planning and floodplain planning. The likelihood of floods in the LCRR basin will change and there is no consensus on how to estimate recurrence intervals for floodplain development regulation.

Preliminary Recommendation on Climate Change:

The multiple approaches to climate modeling employed by the Study all indicated major uncertainty in future water regime with a very low (but not null) probability for larger floods than the flood of 2011, and the potential for more frequent and extended periods of low water levels in the Lake and River.

Therefore, the Study Board recommends that the IJC advise the governments to share existing and new climate scenarios with all interested parties and encourage decision-making bodies to consider climate change in their decision making across all aspects of flood risk management and response.

Combining measures

The Study recognized that dividing the approaches to improving the resilience of the LCRR basin communities to flooding into four themes ran the risk of developing disconnected recommendations and approaches, so efforts were made throughout to maintain and enhance linkages across disciplines, geographies, and cultures. Many diverse communities of experts and impacted residents contributed to the products of the Study, and its success will rely on continued engagement and relationship building. An essential component of success will be combining structural and non-structural measures to deal with high-flows directly, as well as allowing at-risk individuals and assets to be moved out of harm's way or protected under emergency conditions and over the longer term.

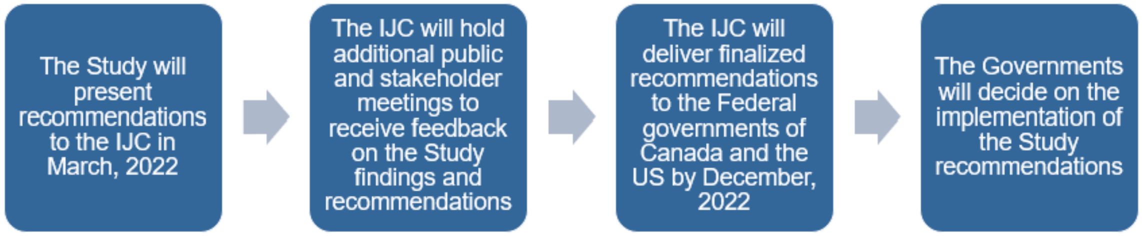
Structural measures alone cannot keep the waters of Lake Champlain and the Richelieu River within their shorelines under all conditions, but they can provide some relief under the worst of high-flow events. To be most effective, however, they need to be used in combination with approaches that reduce exposure to floods, such as adjustment over time in the locations and construction details of buildings and other structures located at or near the shore, preservation of current wetland areas, and improvements in the ways that human and financial risks are communicated, internalized and distributed among communities and individuals. This means that there is not a single **solution** to the problem of flooding in the LCRR basin, but rather a whole suite of "all-of-the-above" approaches that can collectively help LCRR communities become better prepared for future floods.

Binational collaboration

The Boundary Waters Treaty of 1909 between Canada and the United States set forth a commitment between the Parties to jointly "prevent disputes regarding the use of boundary waters and to settle all questions." The question of how best to manage flows and levels in the boundary-spanning LCRR basin has been addressed by this Study, including collaboration with Indigenous governments and communities. The approach included accessing technical experts in water science, engineering and policy, as well as community experts in emergency response and municipal planning. No single individual, community, agency or institution can effectively implement the recommendations of the Study alone. Innovations can arise and lessons can be learned at many scales and at unpredictable locations. Investments of time, energy and resources will be required to continue to improve and maintain flood mitigation measures that will make the region a safer and more resilient place to live.

What comes next?

The IJC plays an advisory role to the Parties and has only limited jurisdiction and resources to manage or enhance transboundary waters such as those of the LCRR basin. The process below will be followed after the Study presents its results to the IJC Commissioners. It is the Parties who will take the actions they deem appropriate.



Over the course of this Study, experts have produced a wealth of data and tools to support the implementation of in integrated flood mitigation strategy for the LCRR basin. The data and tools produced in this Study will be useful for stakeholders in the basin, and potentially elsewhere, to improve community resilience and reduce risks to life and property.